Exhibit E

HTTP/1.1 200 OK
Date: Tue, 09 Apr 2002 06:02:04 GMT
Server: Apache/1.3.20 (Unix)
Last-Modified: Wed, 18 Mar 1998 02:33:00 GMT
ETag: "2e7b41-17dcb-350f325c"
Accept-Ranges: bytes
Content-Length: 97739
Connection: close
Content-Type: text/plain

Internet-Draft ARA March 1998

Expiration Date: May 1998
File name: draft-ietf-ospf-ara-02.txt

The OSPF Address Resolution Advertisement Option

Rob Coltun
FORE Systems
(703) 245-4543
rcoltun@fore.com

Juha Heinanen
Telia Finland, Inc.
+358 303 944 808
jh@telia.fi

Status Of This Memo

"1id-abstracts.txt" listing contained in the Internet- Drafts Shadow Directories on ds.internic.net (US East Coast), nic.nordu.net (Europe), ftp.isi.edu (US West Coast), or munnari.oz.au (Pacific Rim).

Table Of Contents

1.0 Abstract

This document defines an optional extension to OSPF which enables routers to distribute IP to link-layer address resolution information An OSPF Address Resolution Advertisement (ARA) may include media-specific information such as a multipoint-to-point connection identifier along with the address resolution information to support media-specific functions. The ARA option can be used to support router-to-router inter-subnet shortcut architectures such as those described in [HEIN].

2.0 Overview

Along with the evolution of switched layer 2 technologies comes the ability to provide inter-subnet shortcut data switching (bypassing layer-3 forwarding intervention). Before the ingress devices is able to dynamically set up the switched path it must have the link-layer address of the egress device. Acquisition of the egress device's link-layer address may be through configuration or through a dynamic mechanism which resolves an IP address (or an IP end-point identifier) to a link-layer address.

This document introduces a method for IP to link-layer addresses resolution which supports router-to-router and router-to-network inter-subnet shortcuts. Fundamentally, the option provides a mechanism for routers to distribute their IP to link-layer address resolution information (referred to in this document as link-layer associations), and for routers to determine the link-layer association which are closest to their target networks (within an OSPF domain). Address Resolution Advertisements (ARAs) are used to distribute the link-layer associations of routers (Router ARAs) and their directly connected networks (Network ARAs) within and between OSPF areas. Distribution of ARAs is performed using standard OSPF flooding mechanisms. ARA information is encapsulated in Opaque LSAs [OPAQ] and flooded using the mechanisms defined in [OPAQ].

The ARA option supports both topology-derived and data-driven shortcut architectures with this simple extensions to OSPF. This document does not define an architecture but is meant to be used with architectures such as those defined in [HEIN]. The ARA option is designed to support the following types of operations.

Shortcuts between core or access routers within ISP Backbones.

Shortcuts in enterprise networks between routers in the same OSPF autonomous system, between OSPF internal routers and autonomous system border routers (ASBR) or between routers and servers.

Distributed router architectures.

Interoperation with ION NHRP and ATMF MPOA.

Inter-subnet multicast shortcuts using LIJ or Point-to-MultiPoint procedures.

2.1 Acknowledgments

The authors would like to thank Atul Bansal, Lou Berger, Yiqun Cai, John Moy, Stephen Shew, George Swallow and the rest of the OSPF Working Group for the ideas and support they have given to this project.

3.0 Examples

In this section three example ARA topologies are presented for the purpose of explaining the ARA model and capabilities. These examples include a single-area topology with intra-area shortcuts, a multiple-area topology with inter-area shortcuts and an example of shortcuts using the ARA multiple logical network capability.

3.1 Example 1: Intra-Area

Consider the sample single-area topology in Figure 1 below. In this example RT1, RT2 and RT5 support the ARA option (by definition they also support the Opaque LSA option) and RT4 supports the Opaque LSA option only (this is necessary so that RT4 redistributes the ARAs originated by RT1, RT2 and RT5). RT2 and RT5 have each originated a Router ARA (R-ARA) with an intra-area router association and RT5 has originated a Network ARA (N-ARA) with an intra-area network association for N5.

As a result of running the routing table calculation, RT1 has entries for N1-N8 in its routing table. The entry for N2 references the link-layer associations distributed in RT2's R-ARA, the entries for N3, N4, N6, N7, N8 references the link-layer associations distributed in RT5's R-ARA and the entry for N5 references the link-layer associations distributed in RT5's intra-area N-ARA.


```
             +   ARA
             |  +---+                        N3        N5  (ARA)
```

```
       N1|--|RT1|\                        \ N4  /
         |  +---+ \                        \ | /
         +         \                        \|/
                    \+---+                +---+
                     |RT4|------------|RT5|  ARA
                     +---+                +---+
          +   ARA     /                     |      N7
          |  +---+   /                      |     /
       N2|--|RT2|/                          |    /
          |  +---+     +---+              +---+/
          +            |RT3|-----------|RT6|----N8
                       +---+              +---+
                         |
                         |
                    +---------+
                        N6
```

Figure 1: Sample Single-Area Topology

3.2 Example 2: Inter-Area

Consider the sample 2-area topology in Figure 2 below. In this example RT1, RT2, RT3, RT4, RT6 and RT7 support the ARA option, and RT5 supports the Opaque option. N4 is an AS external route (which is flooded to all areas) and RT6 is an ASBR. RT4 is an area-border router and originates an LS Type-4 LSA on behalf of RT6 and a LS Type-3 LSA for N5 into area 1.1.1.1.

Within area 1.1.1.1, RT1, RT2, RT3 and RT4 originate intra-area R-ARAs. Within the backbone RT6 and RT7 originate intra-area R-ARAs and R7 originates a N-ARA for N5. All backbone ARAs of have their the P-bit set (this bit informs ABRs that the ARA may be propagated between areas). RT4 originates an inter-area R-ARA for RT6 (which is an ASBR) as well as an inter-area N-ARA for N5 into area 1.1.1.1 RT4 does not originate an inter-area R-ARA for RT7 because it is not an ASBR.

As a result of running the routing table calculation, RT1 has entries for N1-N5 in its routing table. The entry for N2 references the link-layer associations distributed in RT3's R-ARA, the entry for N3 references the link-layer associations distributed in RT4's intra-area R-ARA, the entry for N4 references the link-layer associations distributed in RT4's inter-area R-ARA (indirectly referencing RT6's R-ARA) and the entry for N5 references the link-layer associations

distributed in RT4's inter-area N5 N-ARA.

```
          +   ARA      ARA       |
```

```
   |  +---+    +---+      |
 N1|--|RT1|----|RT2|\     |        N3           N4<ASE
   |  +---+    +---+ \    |      +-----+          /
   +                  \  ARA        |       ARA  /
                       \+---+    +---+    +---+
                        |RT4|----|RT5|---|RT6|<ASBR
                        +---+    +---+    +---+
             +   ARA   /  |                 |
             |  +---+ /   |                ARA    +
          N2 |--|RT3|/    |               +---+   |
             |  +---+     |               |RT7|---|N5(ARA)
             +            |               +---+   |
 -------------------------|--------------------   +
      Area 1.1.1.1        |     OSPF Backbone
```

Figure 2: Sample Area Topology

3.3 Example 3: Multiple Logical Networks

The ARA option supports the existence of disjoint switched networks within an OSPF domain. To accomplish this, an ARA may include an identifier (the logical network ID) for a specific switched network. When associations are added to the routing table during the OSPF routing table calculation (see the Section 9.1 "Adding ARA Routing Table Extensions") only the associations that include a logical network ID that matches one of the router's configured logical network IDs are added to the routing table. This function may also be used to support a variation of closed user groups so that shortcuts are limited to those routers that are configured to be in the same logical network.

The single-area topology described in Figure 3 below divides an OSPF area into logical networks X and Y. In this example RT1, RT2 and RT4 support the ARA option and RT3 supports the Opaque LSA option only. RT1 is connected to logical network (LN) X, RT2 is connected LN Y and RT4 is connected to both LN X and LN Y. RT1, RT2 and RT4 all originate R-ARAs.

As a result of running their routing table calculation, RT1 and RT2 have entries for N1-N5 in their routing table. In both routing tables, the N3-N5 entries reference the link-layer associations distributed in RT4's R-ARA. However, RT1's routing table does not reference RT2's link-layer associations for N2 and RT2's routing table does

not reference RT1's link-layer associations for N1 (i.e., they would not be able to set up shortcuts to each other and would be forced to use a hop-by-hop path to communicate).

```
      +   ARA (LN=X)
      |  +---+                   N3      N5
    N1|--|RT1|\                    \ N4  /
```

```
     |  +---+ \                    \ | /
     +         \                    \|/
                \+---+             +---+
                 |RT3|------------|RT4| ARA (LN=X,Y)
                 +---+             +---+
                 /
      +   ARA (LN=Y)
      |  +---+ /
   N2|--|RT2|/
      |  +---+
      +
```

Figure 3: Sample Topology With Logical Networks

4.0 A Brief Comparison Of Address Resolution Models

Current models of inter-subnet address resolution have taken the form of a query/response protocol as in the case of [NHRP]. In this model the ingress device originates a resolution request which is forwarded hop-by-hop through a series of NHRP servers towards the destination IP address contained in the request. The the last-hop server (the one that is closest to the destination) responds to the request with the link-layer address that it associates with the requested IP address. The address that is returned may be the address of the requested host system or the address of a router which is on the path to the destination. Upon receiving a response to its request, the ingress device sets up a shortcut path to be used for data transfer. The resolution request mechanism has the following characteristics.

o Routers and hosts may participate in the request mechanism. The participating devices are discovered through polling.

o The request mechanism requires polling by the ingress device to detect topology and reachability changes. Changes in the topology could result in packet loss for the polling interval. Stable routing loops may form as a result of topology changes (given a

limited set of failure conditions and topologies).

o Requests are unreliable and are subject to packet loss.

o It is recommended that the request mechanism be limited to intra-area shortcuts (although with correctly designed topologies this limitation may be over restrictive).

o The target of a request may be a host or network addresses (excluding class D (multicast) networks).

o The response to the request allows the requesting entity to set up a point-to-point shortcut.

Given the above characteristics, the query-response protocol may not be the optimal mechanism for particular applications such as the one described in [HEIN]. The ARA option has the following characteristics.

o Only routers participate in the ARA option. A router's participation in the ARA option is discovered through its address resolution advertisements.

o The ARA option does not require polling by the ingress device to detect topology and reachability changes. Changes in the topology and system reachability may result in packet loss (or transient loops) for the OSPF convergence time. Additionally, since topology changes are determined as a result of OSPF's SPF calculation (which results in loop-free paths), shortcuts derived from the ARA option can never result in stable routing loops.

o Address resolution distribution is reliable and is not subject to packet loss.

o The target of ARA derived shortcuts may be routers and and their connected networks within the OSPF autonomous system. Shortcuts are also supported when the destination is associated with an OSPF AS boundary router advertisement (e.g., networks external to the OSPF autonomous system).

o The ARA option allows the requesting entity to set up point-to-point shortcuts as well as shortcuts that join point-to-multipoint and multipoint-to-point trees.

o Routers that run the ARA option can interoperate with systems running NHRP.

o The ARA option may easily be extended to support inter-subnet multicast shortcuts.

5.0 ARA Components

The ARA option is comprised of several components including Address Resolution Advertisements, the ARA association table, a logical network ID List, routing table extensions and methods for restricting shortcut connectivity. The following sections gives an overview of these components.

5.1 Address Resolution Advertisements

The ARA option defines a set of link-state advertisements called address resolution advertisements (ARAs). ARAs are used to distribute the link-layer associations of routers and their directly connected networks. ARAs are distributed within a single area and may be distributed between OSPF areas. ARA information is encapsulated in Opaque LSAs (see [OPAQ] for a further description of Opaque LSAs). Three LS Types (LS Type 9, 10 and 11) constitute the Opaque class of link-state advertisements. Each of the three Opaque link-state types have a scope associated with them so that distribution of the information may be limited appropriately by the originator of the LSA. Because the flooding scope for ARAs is always area local, ARAs are encapsulated in LS Type 10 LSAs. Opaque LSAs have a sub-type which identifies the specific information that is carried within the LSA. ARA uses Opaque-types 1, 2, 3 and 4. See Section 7.0 for a further description of the ARA packet formats.

5.2 ARA Association Table

A router implementing the ARA option maintains a table of link-layer associations for each of its OSPF areas. The ARA Association Table is used in calculating the ARA routing table extensions and by area border routers in the inter-area ARA origination process. The indexes for an entry in this table are the Vertex Type, Vertex ID and the Vertex Originator. The Vertex Type identifies the type of IP topology element that the link-layer information is being associated with (i.e., a router or a network), the Vertex ID identifies a piece of the OSPF topology (i.e., a router ID or an IP network number) and the Vertex Originator is the Router ID of the router originating the ARA.

5.3 Logical Network ID List

An ARA capable router maintains a configured list of logical networks IDs. This list represents the logical networks that a router is connected to and may be used to restrict the set of devices that the router may setup shortcuts to (see Section 4.5 "Restricting Shortcut Connectivity"). The absence of entries in the router's list of Logical Network IDs means that the router will only activate ARA Association Table entries with the default Logical Network ID (Logical Network ID 0).

5.4 Routing Table Extensions

Associations are added to the routing table during the OSPF routing table calculation (see Section 9.1 entitled "Adding ARA Routing Table Extensions"). That is, in addition to the standard information fields